MAR 05 2003
6830 H05
NAS 1.53/3: 03-OSS-02

National Aeronautics
and Space Administration

FEBRUARY 18, 2003
NRA 03-OSS-02

NASA RESEARCH ANNOUNCEMENT

NEW MILLENNIUM PROGRAM SPACE TECHNOLOGY - 8

NOTICE OF INTENT: MARCH 20, 2003
PROPOSALS DUE: APRIL 18, 2003

20040108722 MH
C

OMB Approval No. 2700-0087

NEW MILLENNIUM PROGRAM
SPACE TECHNOLOGY 8

NASA Research Announcement
Soliciting Applied Research Proposals

NRA 03-OSS-02
Issued: February 18, 2003

Notice of Intent to Propose Due:
March 20, 2003

Proposals Deadline
April 18, 2003

Office of Space Science
National Aeronautical and Space Administration
Washington, DC 20546-0001

NEW MILLENNIUM PROGRAM (NMP) SPACE TECHNOLOGY 8 (ST8)

SUMMARY OF SOLICITATION

1. Summary of the Program

NASA's Office of Space Science (OSS) issues this NASA Research Announcement (NRA) for the New Millennium Program (NMP) to solicit proposals for its Space Technology 8 (ST8) Project flight validation opportunities. The goal of NMP is to validate through flight in space breakthrough technologies that show distinct promise of being able to minimize risk of first use and reduce cost for future space science missions. This NRA solicits proposals from prospective Principal Investigators (PI's) for advanced technology subsystem concept investigations that can be developed for flight validation in the 2005 to 2006 time frame on either an NMP-provided host spacecraft or a PI-identified accommodation for space flight. [Note: The NMP defines a PI as a Technology Provider who is the individual responsible for proposing a flight validation concept and for leading technology development, technology validation, and publication of results. The PI works through their parent organization, partners, the NMP Office, and NASA Headquarters (HQ) OSS to achieve the flight validation experiment objectives.]

NMP characterizes a technology subsystem as one that can be flight validated in space as a stand alone experiment on a host spacecraft. Each proposal selected for this ST8 Project and then down-selected at the end of a Study Phase will enter into a Formulation Refinement Phase. At the completion of the Formulation Refinement Phase the technology subsystem concepts will be reviewed by a NASA OSS Mission Confirmation Review board, and if confirmed, will proceed to the Implementation Phase. The ST8 Project is expected to provide a flight validation opportunity for multiple technology subsystems.

NASA's specific technology subsystem validation needs for ST8 are:

- Deployment of Ultra Lightweight Booms,
- Deployment of Lightweight Solar Array,
- Thermal Management Subsystem for Small Spacecraft, and
- Commercial-Off-The-Shelf (COTS)-Based High Performance Computing for Space.

These technology subsystem validation needs and their respective validation requirements are further described in detail in Appendix A of this NRA.

The ST8 flight validation opportunity is open to U.S. organizations including industry, universities, Federally Funded Research and Development Centers (FFRDC's), NASA Centers, the Jet Propulsion Laboratory, and other U.S. Government agencies. Participation by foreign organizations is permitted, however, NASA policy is to conduct research with foreign entities on a cooperative, no-exchange of funds basis. For further information regarding NASA policy on non-U.S. participation see Appendix B of the *NASA Guidebook for Proposers* as referenced below.

The NMP is subject to the restrictions imposed by Export Administration Regulations (EAR) and International Traffic in Arms Regulations (ITAR). It is incumbent upon the PI to assure the protection and nondisclosure of intellectual property including requirements of the EAR and ITAR. U.S. PI's should be aware that hardware, software, or related materials and services, including technical data, may be subject to U.S. export control laws, including the U.S. Export Administration Act, the Arms Export Control Act, and their associated regulations. It is incumbent upon the U.S. PI's to strictly comply with all U.S. export control laws, and, when applicable, assume the responsibility for obtaining export licenses, or other export authority as may be required, for hardware, software, and related materials and services, including technical data, related to the performance of this NRA that are in its possession or under its control.

Note that safety is a prime concern for NASA programs. Safety is the freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment. NASA's safety priority is to protect: (1) the public, (2) astronauts and pilots, (3) the NASA workforce (including employees working under NASA award instruments), and (4) high-value equipment and property.

Recommendations for selection of the proposals submitted to this NRA will be based on a NASA peer review evaluation of each proposal's intrinsic merit, its relevance to NASA's objectives, and its cost as set forth in Appendix C of the *NASA Guidebook for Proposers* as referenced below. Note that cost evaluations will be made on the proposed cost for the six month Study Phase and the cost estimate for the anticipated Formulation Refinement and Implementation Phases as described in Section 2 of this Summary of Solicitation.

Provided that proposals of sufficient merit are submitted, up to ten proposals may be selected for a six month Study Phase. The NMP contemplates Study Phase contracts (or other agreements as appropriate for government organizations) in the range of $200K to $500K each. At the conclusion of the Study Phase, each selected PI will be required to deliver a Study Phase Report that demonstrates that their proposed technology subsystem investigation is sufficiently mature to warrant flight validation in the 2005/2006 timeframe, and includes a detailed plan for conducting Education and Public Outreach (E/PO) activities. Summary draft guidelines for the Study Phase Report are provided in a separate document entitled *Draft Guidelines for the Content of the NMP ST8 Study Phase* that is accessible in the NMP ST8 document library at the World Wide Web URL http://nmp.jpl.nasa.gov/st8-lib. Each Study Phase Report must conclude with a

commitment by the PI for the cost, schedule, and technical performance of the investigation. If at any time the cost, schedule, or technical performance commitments appear to be in peril, the investigation will be subject to cancellation since the NMP does not maintain a budget reserve.

The Study Phase Reports will undergo a peer review process, and it is anticipated that approximately half of the Study Phase investigations may be selected to continue into the Formulation Refinement Phase. At the investigation's Confirmation Review for Implementation, the PI will be required to demonstrate a minimum cost reserve of 30% against the cost to complete, or to justify why a cost reserve of less than 30% against the cost to complete is adequate. Investigations that proceed to flight validation are required to deliver a Final Report to NASA no later than six months after the flight of any hardware and/or software. Documentation of technology performance, technology validation results, and correlation of results with models or predictions are required as part of the Final Report. Detailed requirements for this report will be incorporated into the contracts (or other agreements) for the Implementation Phase.

The total funding available for the ST8 Project for all phases and for all technology subsystem concepts is approximately $40 million in real year dollars through flight and issuance of final reports. Although proposers may cost their complete investigation at any level within the $40 million budget, based on previous experience it is anticipated that the final program may have no more than one award between $8M to $12M, plus up to four awards between $5M to $8M, plus up to two awards less than $5M.

Note that this NRA will be the only opportunity to propose to participate in the ST8 Project as a PI. In all cases, NASA's obligation to approve contract (or other agreement) awards is contingent upon the availability of funds and the receipt of proposals that NASA determines are acceptable.

2. Instructions For Preparation And Submission Of Proposals

Unless otherwise specified in this NRA, the policies and procedures for the preparation and submission of proposals, as well as those for NASA's review and selection of proposals for funding, are provided in a separate document entitled *Guidebook for Proposers Responding to NASA Research Announcements* (abbreviated as *NASA Guidebook for Proposers*) that is accessible by opening the single Web portal for the submission of proposals to any of the NASA program offices at the World Wide Web URL http://research.hq.nasa.gov/, and linking through the menu item "Helpful References," or it may be directly accessed at URL http://www.hq.nasa.gov/office/procurement/nraguidebook/. By reference, this *NASA Guidebook for Proposers*, Edition: 2003 is hereby incorporated into this NMP ST8 NRA, and proposers to this NRA are responsible for understanding and complying with its procedures before preparing and submitting their proposals. Proposals that do not conform to its standards may be declared noncompliant and returned without review.

For this NRA, the proposal page limit for the Scientific/Technical/Management Section is increased to 18 pages instead of 15 as specified in Section 2.3 of the *NASA Guidebook for Proposers*. In addition to the required topics specified in Section 2.3.4, Scientific/Technical/ Management, of the *NASA Guidebook for Proposers*, proposers to this NRA are required to provide the following information:

- Statement of rationale for requiring a space flight validation of the proposed technology subsystem concept, and a specification of the required space environment for the proposed technology investigation;
- Justification that the proposed technology subsystem concept is currently at a Technology Readiness Level (TRL) 3 or higher (TRL definitions are provided in a separate document entitled *Technology Readiness Level Description for the New Millennium Program* that is accessible in the NMP ST8 document library at the World Wide Web URL http://nmp.jpl.nasa.gov/st8-lib);
- Description of Study Phase activities that will demonstrate how future hardware and software deliverables will be at TRL 4 or higher at the conclusion of the Study Phase;
- Description of the plan for attaining TRL 5 or higher at the end of the Formulation Refinement Phase and establishing readiness for a technology validation flight in 2005 or 2006;
- Description of the flight validation plan, specification of the proposed technology to be tested and associated performance parameters to be measured during space flight, and description of the relationship of the performance parameters to both the rationale for space flight validation and the specified space environment;
- Specification of any mathematical or scaling models to be used to predict performance parameters of the flight experiment and to predict the performance of future implementations, a discussion of the extent to which these models have been verified prior to the validation flight, and a discussion of the degree to which the flight validation data will provide further verification of these models; and
- Specification of the approach proposed for access to space (proposers should identify any non-NMP partnerships as applicable; should an NMP-provided accommodation be desired, the proposer should identify the technology validation requirements that must be met by an NMP-provided space platform, including requirements for mass, power, volume, mechanical interface, telemetry data rate and storage, pointing, thermal control, and operations, as well as any flight and/or orbit constraints).

Proposers must provide budget data for a six month Study Phase, per Section 2.3.10, Budget Summary and Details, of the *NASA Guidebook for Proposers*, except assume a start date of five months instead of seven months after proposal submittal. Proposers are also required to provide a cost estimate for the anticipated Formulation Refinement and Implementation Phases.

Note that the *NASA Guidebook for Proposers* provides supplemental information about the entire NRA process, including NASA policies for the solicitation of proposals, guidelines for writing complete and effective proposals, the NASA policies and procedures for the review and selection of proposals, as well as for issuing and managing

the awards to the institutions that submitted selected proposals, and Frequently Asked Questions (FAQ's) about a variety of the NASA proposal and award processes and procedures.

The World Wide Web site for submitting both a Notice of Intent (NOI) to propose, which is encouraged but not required, and a Proposal Cover Page/Proposal Summary and Budget Summary is given in Section 5, Summary Information Applicable to this NRA, below (note that Chapters 2 and 3 of the *NASA Guidebook for Proposers* contain detailed information about these two items). After logging into the HQ data system at this Web site, a menu entitled "Division Specific Opportunities" will be presented. In order to gain access to the site for this NMP ST8 NRA, select "OSS Sun Earth Connection." Note that all applicants to this NRA, whether as PIs or Co-Is, must be registered with the database at this Web site in order for a Cover Page containing their names to be electronically submitted.

3. OSS Education And Public Outreach Program

The OSS is committed to fostering the broad involvement of the space science community in Education and Public Outreach (E/PO) with the goal of enhancing the Nation's formal education system and contributing to the broad public understanding of science, mathematics, and technology. Progress towards achieving this goal has become an important part of the broad justification for the public support of space science.

As a consequence of the plans and policies that have been established and implemented over the past several years, a significant national E/PO space science program is now underway as described by the OSS E/PO Newsletters and the Annual Reports that may be accessed by opening the "Education" link on the OSS homepage at http://spacescience.nasa.gov. This site also provides access to the two key documents that establish the basic policies and guidance for all OSS E/PO activities: A strategic plan entitled *Partners in Education: A Strategy for Integrating Education and Public Outreach Into NASA's Space Science Programs* (March 1995), and an implementation plan entitled *Implementing the Office of Space Science Education/Public Outreach Strategy* (October 1996). Both of these documents may also be obtained in hard copy from Dr. Jeffrey D. Rosendhal, Office of Space Science, Code S, NASA Headquarters, Washington DC 20546; E-mail: jeffrey.rosendhal@hq.nasa.gov.

A summary of the key elements of the current OSS E/PO program that apply to this NRA are as follows:

- An E/PO plan must be included as part of the Study Phase Report;
- E/PO plans will play an explicit role in the evaluation of the Study Phase Reports and in the selection of investigations that will continue into the Formulation Refinement Phase;
- The E/PO project budget should be approximately 1% of the total proposed budget for Formulation Refinement and Implementation;

- Each NMP Project will conduct its E/PO activities in accordance with its E/PO Plan, which shall include provisions for providing technical expertise in support of the overall NMP E/PO Program; and
- Each project's E/PO activities shall emphasize technology education rather than science education, and should have a direct intellectual link to the technologies being developed by the project.

For further information regarding NMP E/PO activities, visit the NMP Website, http://nmp.jpl.nasa.gov and the "Spaceplace" http://spaceplace.jpl.nasa.gov/, or contact Ms. Nancy Leon (telephone: (818) 354-1067; E-mail: Nancy.J.Leon@jpl.nasa.gov). Questions and/or comments and suggestions about the OSS E/PO program are sincerely welcomed and may be directed to either Dr. Philip Sakimoto (telephone: (202) 358-0949; E-mail: phil.sakimoto@hq.nasa.gov), Ms. Rosalyn Pertzborn (telephone: (202) 358-1953; E-mail: rpertzbo@hq.nasa.gov), or Dr. Larry Cooper (telephone (202) 358-1531; E-mail: lcooper1@hq.nasa.gov.

4. Items of Special Importance

(i) If additional programmatic information develops before the proposals are due, such information will be added as Amendments to this NRA as posted at its Web site. Although NASA OSS will also send an electronic notification of any such amendments to all subscribers of its electronic notification system (see item (iii) below), it is the responsibility of prospective proposers to check this NRA's Web site for updates.

(ii) OSS requires the electronic submission of certain key elements of proposals through the World Wide Web (see below in Section 5, Summary Information Applicable to the NRA). While every effort is made to ensure the reliability and accessibility of this Web site, and to maintain a Help Desk via E-mail (proposals@hq.nasa.gov), difficulty may arise at any point on the Internet including the user's own equipment. Therefore, prospective proposers are urged to familiarize themselves with this site and to submit the required proposal materials well in advance of the deadlines.

(iii) OSS maintains an electronic notification system to alert interested subscribers of the impending release of its research program announcements. Subscription to this service is accomplished through the menu item "To subscribe to the OSS electronic notification system" found on the menu of the OSS research page at http://research.hq.nasa.gov/code_s/code_s.cfm. Owing to the increasingly multidisciplinary nature of OSS programs, this electronic service will notify subscribers of all NASA OSS program announcements regardless of the type and science objectives (about 25 per year). Regardless of whether or not this service is subscribed to, all OSS research announcements may be accessed from the menu listing Current (Open) Solicitations at the Web site given above as soon as they are posted (typically by 8:30 a.m. Eastern Time on their date of release).

5. Summary Information Applicable to this NRA

Program Alpha-Numeric Identifier	NRA 03-OSS-02
Date of NRA Release	February 18, 2003
Access to text	Link through the menu listings Research Solicitations, Current (Open) Solicitations starting from the OSS home page at http://spacescience.nasa.gov/.
Guidance for preparation and submission of proposals	*NASA Guidebook for Proposers Responding to a NASA Research Announcement (NRA)* – 2003 at URL http://www.hq.nasa.gov/office/procurement/nraguidebook/
Notice of Intent (NOI) to Propose (encouraged but not required):	
- Desired due date	March 20, 2003
- Web site for electronic submission	Open appropriate menu listing at http://research.hq.nasa.gov/ (available for submissions for ~30 days starting ~30 days from release of the NRA Deadline (Help Desk E-mail: proposals@hq.nasa.gov)
- Late submission (up to 5 days prior to Proposal Deadline)	Submit information specified in Section 3.1 of *NASA Guidebook for Proposers* by E-mail to proposals@hq.nasa.gov
Proposal Cover Page (including Proposal Summary and Budget Summary):	
- Deadline	(Same as for proposals) Print completed items from Web site http://research.hq.nasa.gov/
- Web site for electronic submission	Same as above (open for submissions starting ~ 45 days prior to Proposal Deadline) (Help Desk E-mail: proposals@hq.nasa.gov)

Proposal page limits	18 pages as specified in Section 2 of this NRA.
Submission of proposal: - Required Number - Deadline - Address for submission by U.S. Postal Service, commercial delivery, or private courier	 Signed original proposal plus 30 copies (including printed Cover Page/Proposal Summary and Budget Summary). The Technical/Management portion and the Cost Proposal portion should be submitted as separate documents. 4:30 p.m. Eastern Time on April 18, 2003 NMP ST8 NRA Office of Space Science NASA Peer Review Services 500 E Street, SW, Suite 200 Washington, DC 20024 Telephone: (202) 479-9030
Selecting Official	Associate Administrator for Space Science
Announcement of selections	Goal: 150 days after Proposal Deadline
Initiation of funding for new awards	Goal: 46 days after proposal selections
Further information: - Programmatic contact - For general NRA policies and procedures	 Mr. Charles Gay New Millennium Program Executive Code SS Office of Space Science Washington, DC 20546-0001 Telephone: (202) 358-2387 E-mail: Charles.Gay@hq.nasa.gov Dr. J. David Bohlin Office of Space Science NASA Headquarters Washington, DC 20546-0001 E-mail: David.Bohlin@hq.nasa.gov

Your interest and cooperation in responding to this NRA are appreciated.

Richard R. Fisher
Director
Sun-Earth Connection Division

Colleen N. Hartman
Director
Solar System Exploration Division

Anne L. Kinney
Director
Astronomy & Physics Division

Edward J. Weiler
Associate Administrator
for Space Science

NEW MILLENNIUM PROGRAM (NMP) SPACE TECHNOLOGY 8 (ST8)

Description of Opportunity

This NRA solicits proposals from prospective PI's for advanced technology subsystem concepts that can be developed for flight validation in the 2005/2006 time frame, on either an NMP-provided host spacecraft or on one identified by the proposer.

The technical areas and related objectives for which proposals are specifically solicited under this NRA are listed below. Proposers or teams of proposers may submit multiple proposals; however, each proposal shall address only one of the following technologies areas:

- Deployment of Ultra Lightweight Booms
- Deployment of Lightweight Solar Array
- Thermal Management Subsystem for Small Spacecraft
- Commercial-Off-The-Shelf (COTS)-Based High Performance Computing for Space

The following sections of this Appendix address each of these technology areas by first presenting the flight validation concept, which includes the anticipated technology benefit, a description of the flight validation objective, and the rationale for flight validation. Science mission applicability, representative space experience, technology performance requirements, and representative measurement, parameter and model verification needs are then presented. Further information on missions discussed in the science mission applicability sections can be found on the following NASA websites:

Office of Space Science (OSS):	**http://spacescience.nasa.gov/**
NASA OSS theme websites:	
Exploration of the Solar System (ESS):	**http://sse.jpl.nasa.gov/**
Structure and Evolution of the Universe (SEU):	**http://universe.gsfc.nasa.gov/**
Sun Earth Connection (SEC):	**http://sec.gsfc.nasa.gov/**
Astronomical Search for Origins (ASO):	**http://origins.jpl.nasa.gov/**

A.1 DEPLOYMENT OF ULTRA LIGHTWEIGHT BOOMS

A.1.1 Flight Validation Concept

Technology Benefit and Description: Ultra lightweight deployable structures represent a fundamental technology upon which a myriad of future space applications depend. They are an enabling technology for large membrane structures such as solar sails and telescope sunshades,

71

solar array assemblies, large aperture optics, instrument booms, and antennas by offering significant mass savings and compact volumes for easy packaging for launch.

Conventional spacecraft structure is a predominant portion of spacecraft mass. Large ultra lightweight booms can reduce the mass of spacecraft attributed to structure, but their deployment in space requires validation of several key technologies. Among these are deployment mechanisms, techniques for determining that the deployed boom is securely in place, control of deployment dynamics, and the effects of attachments and loads on static and dynamic performance. Many of these technologies require validation in the microgravity and high vacuum environment found only in space. Successful completion of a validation flight will resolve major uncertainties associated with ultra lightweight structures in space, and will facilitate infusion of ultra lightweight booms into fully functional deployable systems.

Flight Validation Objectives: The objectives of an investigation directed to this technology area should be:

- Validation of boom deployment, including the dynamics and uniformity of the deployment action and the completeness with which the boom secures into its final state of deployment;
- Characterization of the structural mechanics and dynamics of the deployed booms; and
- Validation of design approach and predictive methods for deploying ultra lightweight booms by correlating flight measurements with analytical models developed through ground testing.

To minimize the experiment mass and cost, NASA desires that the selected validation experiment design will focus on booms for large membrane structures. The deployed boom need not be full scale; however, the performance of a subscale system must be scalable to sizes applicable to future space science missions. The proposer needs to identify particular approaches to both boom deployment and boom design, and the rationale for these choices must be discussed in proposals in terms of the breadth of the applications addressed. The NMP envisions that the pathway to maximizing the application envelope and to reducing experiment cost is through developing a scaleable validation experiment and through using validated models to address future designs.

Flight Validation Rationale: Ground testing cannot adequately simulate the deployment dynamics and effects of microgravity on boom performance and structural stability experienced in a space environment. Testing in space is required not only to validate the deployment performance, but also to establish the validity of modeling tools used to design ultra lightweight booms and to predict their structural behavior over a range of design conditions.

A.1.2 Science Missions Applicability

Ultra lightweight structures will enable or benefit several future NASA science missions that employ solar sails, solar arrays, large apertures, and telescope sunshades. Examples of applicable missions include the following:

- ***Sun Earth Connection (SEC)***: Solar Polar Imager (SPI), Magnetospheric Multi-Scale (MMS), Solar Sentinel (GeoStorm);
- ***Structure and Evolution of the Universe (SEU)***: Advanced Radio Interferometry between Space and Earth (ARISE); and
- ***Astronomical Search for Origins (ASO)***: Terrestrial Planet Finder (TPF), Filled Aperture InfraRed (FAIR), Life Finder (LF).

A.1.3 Representative Space Experience

Booms of multiple configurations have been an important feature of numerous spacecraft. Recent examples include the Galileo and Cassini missions that deployed magnetometer booms and the Shuttle Radar Topography Mission (SRTM) mission that used a boom to support an outboard radar experiment. Key characteristics of the Cassini and SRTM booms are given in the table below:

Deployed Boom Characteristics

Missions Involving Boom Deployment	Boom Length (m)	Boom Mass per Unit Length (kg/m)
Cassini	10	0.5
SRTM	60	4.8

A.1.4 Technology Performance Requirements

There must be at least two boom deployments proposed for this investigation to provide a representative set of test data to characterize repeatability. The booms may be of different lengths to help verify scalability. In order to ensure that the flight validation results are readily applicable to future space science missions, the articles proposed to be flown shall meet the following requirements:

- Minimum length: 30 m, scaleable to at least 100 m
- Mass/length: < 0.075 kg/m for the boom itself, excluding deployment devices
- Stiffness: EI > 1000 N-m^2
- Packing factor: < 10 (Packing factor is the ratio of the stowed volume to boom material volume and indicates the amount of dead space contained in the package)

A.1.5 Representative Measurements, Parameters, and Model Verification

This in-space investigation will provide relevant environment test results that can be used to validate the performance models. Hence, the deployed subsystem should be adequately

instrumented to verify successful deployment and to quantify predicted structural characteristics of the booms as follows:

- Deployment dynamics and reaction forces imparted to the experiment platform during deployment;
- Time required to execute the deployment (and rigidization, if inflatable);
- Power required over the deployment period;
- Deployed boom length, straightness, and uniformity;
- Mechanical stability in response to quasi static loads and temperature changes; and
- Structural dynamics, including natural frequency, mode shape, and damping.

A.2 DEPLOYMENT OF LIGHTWEIGHT SOLAR ARRAY

A.2.1 Flight Validation Concept

Technology Benefit and Description: Lightweight solar arrays at the multi-kilowatt level promise greater than a factor three increase in power per unit mass of spacecraft power systems over that which is currently achieved in space. However, the flimsiness of these structures and the uncertainties in deployment mechanisms and dynamics when in space preclude ground validation of their deployment characteristics. A space validation experiment is required to verify the deployment technology and to characterize the effect of space environment on the structural dynamics and power generating performance of these ultra lightweight arrays.

The need for electric power is universal to space missions, and the power subsystem on most spacecraft constitutes a substantial fraction of the entire spacecraft mass. The infusion of the recent technology advances experienced by photovoltaics and lightweight structures into spacecraft solar arrays would both decrease this mass and increase the subsystem's power generation capability. This investigation will merge the best features of these improvements in a validation of the next significant step toward the technology advancement of low mass deployable solar arrays. The efficient use of structure to optimize the panel's electrically active area, coupled with an innovative use of materials and power enhancement strategies to maximize electrical output per unit mass, would favorably impact payload selections for future space science missions and thus enhance science return. The new solar array technology will emphasize compact stowage in order to minimize stowed volume for pre-launch packaging. However, a compactly folded lightweight structure introduces issues of structural dynamics and controllability when it is deployed. Hence, this investigation should study the well controlled deployment of the structure, resulting in the rapid damping of any induced vibration that may have been experienced by its members. This demonstration of a successful deployment will mitigate concerns over the handling of lightweight power generating structures and will be a major contribution to future applications of this technology.

Flight Validation Objectives: The overall objectives of an investigation directed to this technology area should be:

- Characterization of the deployment, controllability, and structural dynamics of a lightweight solar array assembly;
- Verification of the predicted structural and photovoltaic performance of the deployed solar array, including the behavior and durability of the photovoltaics, any supplemental optics, and panel materials in the space environment;
- Verification of secure deployment after the solar array is deployed;
- Verification that the deployed solar array is dynamically stable;
- Validation of photovoltaic cell, blanket, and solar array technology that is capable of being qualified for future NASA missions; and
- Validation of all structural and electrical performance models used to scale up to 7 kW (if flight demonstration is subscale and/or not fully power producing).

The power level for this validation experiment is to be scaleable to 7 kW. To minimize the experiment cost, the deployed array need not be either full scale or fully populated with photovoltaic devices. Therefore, a subscale validation experiment (< 7 kW) can be proposed. However, the performance of a subscale and/or partially populated flight experimental array must reasonably validate the specific objectives of this experiment up to a full 7 kW design. The proposer should also discuss how the performance results of this subscale experiment are scalable to sizes and electrical power requirements applicable to future space science mission needs. The proposer needs to identify particular approaches to both solar array deployment and array design, and the rationale for these choices must be discussed in terms of the breadth of the applications addressed. NMP envisions that the pathway to maximizing the application envelope and to reducing experiment cost is through developing a scaleable validation experiment and through using validated models to address future designs.

The proposer should discuss the tradeoff space in which the various array parameters and features are compared. For instance, a strong mass driver for this technology is the need to size the solar array for its end of life performance. Depending upon the specific mission, radiation induced losses for solar arrays can range from 1 to 2% per year in benign environments such as low Earth orbits, to as much as 50% of its power generating capability per year in higher radiation environments, typical of those found in mid Earth orbits and many planetary encounters. The resulting mass saving from a selection of technologies that maximize photovoltaic efficiency while exhibiting minimal performance degradation over time is sought.

The proposal should also include discussions of various other solar array attributes important to increasing system and spacecraft level performance and to surviving the unique environmental conditions imposed by the wide range of NASA missions. For example, the capability of the array to operate effectively at distances to five Astronomical Units (AU's), is essential for many NASA missions. Array dynamics must be well understood to minimize any adverse impacts during spacecraft maneuvers and science gathering encounters. Proposers should include electrical design concepts and should discuss the tradeoffs among structural, mass, intercell connections, panel connections, and voltage/power at the spacecraft bus.

Higher operating voltages also provide significant system benefits that are synergistic with electric propulsion missions. While not all of these array features may be achievable for any

given experiment, as many as practical should be incorporated so as to provide the broadest possible support to the wide range of NASA missions.

Technology Validation Rationale: A microgravity and space plasma environment, both of which affect the array deployment and the behavior and electrical performance of the deployed panels, cannot be adequately simulated on the ground. Testing in space is not only required to demonstrate successful deployment, deployed array dynamics and in-space performance under combined solar and environmental conditions but it is also needed to establish the validity of modeling tools used to design lightweight structural assemblies, especially for the very large arrays required for missions using electric propulsion.

A.2.2 Science Missions Applicability

Ultra lightweight solar arrays are applicable to all NASA missions for which the Sun can provide an adequate power source, typically missions destined for operation in the inner five AU's of the Solar System.

A.2.3 Representative Space Experience

The current state of the art for solar array capabilities is represented by the Solar Concentrator Arrays with Refractive Linear Element Technology (SCARLET) array, which flew on the NMP Deep Space-1 (DS1) mission. Its characteristics are identified in the table below. Specific details of the SCARLET solar panel can be found at the following website: http://nmp.jpl.nasa.gov/ds1/tech/old/tech2.html

SCARLET Solar Array Capabilities

Array Type	Power Density (W/kg)	Array Output (V DC)
SCARLET Array	50	~100

As a goal, the validation experiments should strive for a fourfold increase in the power density from that of the SCARLET array as a desired next step of technology advance.

A.2.4 Technology Performance Requirements

In order to ensure that the flight validation results are readily applicable to future space science missions, the experiment must demonstrate at least the following characteristics:

- First mode natural frequency: > 0.1 Hz;
- Array sufficiently populated to demonstrate a power density ≥ 175 W/kg at 7 kW per deployed array at 1 AU at beginning of life;
- Power output when extrapolated to a fully populated, full size array ≥ 7 kW at 1 AU at beginning of life;
- Stowed array specific volume: < 0.22 m^3/kW at 7kW; and

- Power per deployed array: ≥ 500 W populated in a manner representative of flight solar arrays, to provide a representative simulation of a fully populated array while minimizing cost.

A.2.5 Representative Measurements, Parameters, and Model Verification

The principal objective for this in-space experiment is to provide relevant environment information that can be used to validate the performance models. Hence, the deployed subsystem should be adequately instrumented to verify successful deployment and to quantify predicted power generation characteristics of the array. The instrumentation should measure parameters that characterize the solar array performance in terms of:

- Deployment dynamics and reaction forces imparted to the experiment platform during deployment;
- Structural dynamics of deployed array, including natural frequencies, mode shapes, and damping;
- Dimensional stability and change in array pointing angle in response to temperature changes; and
- Variation of voltage and current output as a function of time, temperature, and environmental conditions as measured at the spacecraft.

If a subscale deployment structure is selected, then the dynamics of the deployed configuration must be verified to be applicable to a full size array.

A.3 THERMAL MANAGEMENT SUBSYSTEM FOR SMALL SPACECRAFT

A.3.1 Flight Validation Concept

Technology Benefit and Description: The need for mass savings becomes ever more critical as spacecraft sizes shrink to accommodate smaller and more efficient payloads, and advances in thermal control technologies are an integral part in meeting this requirement. There is a critical need for advanced thermal control technology that would allow the low mass, low power, and compactness necessary for future spacecraft. This new technology would not only save mass but it would also enable design flexibility in component placement (i.e., free of thermal constraints) and minimize – if not eliminate – the need for supplemental electrical heaters.

Heat inputs to a spacecraft are derived from numerous internal and external sources: internal via heat dissipation from electronic components and external from the Sun and Earth or other planets encountered. The mass associated with thermal control has typically been 4 to 6% of that of the total spacecraft. The conventional design approach for spacecraft thermal control systems is to couple hotter components directly to a radiator and radiate their waste heat to space, while simultaneously adding electrical heaters to colder components in order to maintain their temperatures. In addition, mass that is not explicitly budgeted as thermal control is often added to various components solely to enhance heat conduction. These conventional practices lead to inefficient use of available power resources and limits the location of individual components

within the spacecraft. Successful validation of an advanced thermal control technology that would maximize the mass savings and minimize or eliminate the need for supplemental electrical heaters would be a major contribution toward the advancement of small spacecraft.

Flight Validation Objectives: The objectives of an investigation directed to this technology area should be:

- Validation of the performance of a thermal control subsystem designed specifically for small (< 150 kg) spacecraft having a total power generation of ≤250 W and corresponding power dissipation of ≤200 W (the spacecraft operating temperature range is provided in Section A.4.4 below);
- Validation of analytically predicted savings in spacecraft mass, power, and volume of thermal control system designed for small spacecraft when compared with conventional thermal control techniques; and
- Validation of analytical models used to predict thermal performance of optimized component locations enabled by new thermal control system.

The NMP seeks to validate advanced thermal control technology that would aid in reducing the mass and power of small spacecraft, where small spacecraft are defined as being lighter than 150 kg. To this end, the proposer is encouraged to suggest methodologies that not only save mass but would also minimize the need for electrical heaters, both of which would enable greater flexibility in the placement of the various components within the spacecraft. Packing flexibility is especially critical for small spacecraft that need to be optimized for mass and volume.

While any concept with a sound rationale for space validation is admissible, the proposed investigation needs to compensate for the fact that the desired operating temperature ranges in the spacecraft environment differ from component to component. The proposed thermal control system must effectively manage components requiring both heat removal and supplemental heating simultaneously.

The proposer must discuss how the performance results for this experiment are scalable to sizes and thermal management needs applicable to future space science missions with small spacecraft. The proposer also needs to identify a particular approach to the design of the validation investigation, including the choice of various components and methodologies, and the rationale for this choice must be discussed in terms of the richness of the applications addressed. Deep space will be the common heat sink for these experiments. The experiment results should validate the design principles used in models to predict and optimize thermal control performance.

Flight Validation Rationale: Validating the effectiveness of minimizing a thermal control system within small spacecraft wherein component placement has been optimized for mass and volume cannot be adequately simulated on the ground. The performance of an advanced thermal control system in a microgravity environment cannot be immediately predicted and must be validated in space. In-space testing will validate both the thermal control operational procedures and the modeling tools used to predict the performance of these systems over a range of design and environmental conditions relevant to future missions.

A.3.2 Science Missions Applicability

Implementation of innovative thermal management systems that yield significant spacecraft power and mass savings will benefit several future NASA missions, including the following:

- ***Mars Missions:*** Mars Science Laboratory, Mars Scouts
- ***Sun Earth Connection Theme:*** Magnetospheric Constellation, Solar Sentinels

A.3.3 Representative Space Experience

Examples of representative innovative thermal management systems implemented on prior NASA missions are:

a) The Capillary Pumped Loop 3 (CAPL3) Flight Experiment flown on STS-108 in 2001 used a capillary pumped loop with one inch diameter evaporators and anhydrous ammonia as the working fluid. It was designed to maintain four separate components with unequal power dissipations at the same temperature. Power dissipation per evaporator ranged from 25 W to 775 W, and system operating temperatures were set at 0, 20, and 30 °C. Component temperatures were maintained while radiator temperatures varied between –45 °C to +15 °C.
b) The active heat rejection system on the Mars Pathfinder cruise stage used Refrigerant 11 in a mechanically pumped liquid loop to control temperatures of various parts of the spacecraft, which was the first application of an active heat rejection subsystem on a deep space mission.
c) A loop heat pipe is used on the Tropospheric Emission Spectrometer (TES) instrument on the Aura spacecraft that will be launched into low Earth orbit in 2003.

A.3.4 Technology Performance Requirements

The thermal management subsystem must maintain spacecraft component mounting surface temperatures within their required operating temperature limits as listed below:

- Batteries: 0 to 20 °C (temperature between multiple battery units $\pm$ 5 °C)
- Power regulating units: 0 to 40 °C
- Momentum wheels: -5 to 45 °C
- Transponders: 0 to 50 °C
- Electronics units: -10 to 40 °C
- Hydrazine propellant: between 13° C and 30° C

Appropriate ground tests must be performed to verify expected performance, as well as to develop appropriate operating procedures such as thermal system start up and shutdown. Adjustments to these procedures due to differences in the ground and space environments are to be noted and verified as part of this experiment.

A.3.5 Representative Measurements, Parameters, and Model Verification

The thermal management subsystem is to be instrumented to the extent required to quantify all necessary parameters that characterize subsystem performance, including but not limited to:

- Component power dissipations;
- Component temperature, including temperature measurements of spacecraft surfaces that may affect the performance of the subsystem; and
- Any electrical power associated with control of the subsystem.

A model of a conventional thermal management subsystem for maintaining the component operating temperature ranges identified above must also be prepared for comparison with the performance results obtained from the flight experiment. The conventional thermal management subsystem is based on conduction and radiation heat transfer mechanisms. The mass of this conventional subsystem and additional electrical heater power required to maintain the colder components within their respective temperature ranges is to be compared with that of the associated flight experiment. The validated models are to be used to design thermal management systems for a range of design conditions, including a significantly larger number of dissipating components at different required temperatures, temperature controllability, and dissipated powers.

A.4 COTS BASED HIGH PERFORMANCE COMPUTING

A.4.1 Flight Validation Concept

Technology Benefit and Description: Onboard high performance, low power computing for science and autonomy data is required on many future NASA space science missions. In many cases, it is envisioned that these high performance computing systems will be used as an adjunct to a radiation hardened ultra reliable spacecraft control computer and associated avionics, acting as compute servers or as instrument processors. Specific usage will ultimately depend on the specific mission requirements.

The potential benefits of COTS high performance computing include significant increase in onboard science data processing enabling orders of magnitude reduction in required communication bandwidth for science data return, orders of magnitude improvement in onboard mission planning and critical decision making, the ability to rapidly respond to changing mission environments, thus enabling opportunistic science, and orders of magnitude reduction in the cost of mission operations through reduction of required mission operations staff.

Additional benefits of COTS-based high performance computing include the ability to leverage the considerable commercial and academic investments in advanced computing tools, techniques and infrastructure, and the familiarity of the science and IT community with these computing environments, models and paradigms.

Future missions utilizing hundreds of Millions of Instructions Per Second (MIPS) to Billions of Instructions Per Second (GIPS) and capable of supporting billions of bytes of memory (GB) are

envisioned to fly in small spacecraft with only a few tens of Watts of power available to the computing system. This experiment seeks to validate technologies that will allow such systems to be developed for space science missions in the next decade.

Investigations are solicited that will validate the ability of commercially based computing systems to provide reliable, low power operation at one to two orders of magnitude higher throughput than state of the art radiation hardened flight computing systems. Ground based testing of COTS processors and other digital Complementary Metal Oxide Semiconductor (CMOS) components over the past three generations has shown a trend towards increased levels of radiation tolerance, allowing the possibility of a COTS-based space borne computer as an attractive alternative or high performance adjunct to radiation tolerant systems for space science missions in relatively benign radiation environments. The technology being validated in this experiment is specifically the system architecture, the analysis tools and methods used to design the system, and the fault tolerance techniques used to provide reliable operation in a space radiation environment, and not the specific COTS components used to implement the system. The general trend of COTS components towards higher levels of Total Ionizing Dose (TID) tolerance and relatively constant Single Event Upset (SEU) and Single Event Latch Up (SEL) tolerance, however, will be validated as a byproduct of this investigation.

It is desired that the experimental system used in the technology validation investigation incorporate all significant components of a flight computing system. It is also desired that the experimental system be operated in a range of radiation environments and that the investigation validate both the expected error rates and the recovery capability of these types of fault tolerant COTS-based systems, thus validating the underlying models and techniques used in designing the system. In validating these models, it is desired that sufficient characterization measurements be performed that any discrepancies between the model predictions and the experimental results can be used to track down the source of the discrepancy and to recalibrate the models. The experimental system must be connected to a known reliable computer, which will monitor its operation and report its health and status throughout the investigation. In addition, measurement of the experiment environment is required to allow correlation of system performance to environmental parameters.

***Flight Validation Objectives*:** The general objective of this experiment is to verify the feasibility of flying a high performance COTS-based data processing system onboard NASA spacecraft. Specific objectives are:

- Validation of the radiation fault models, system models, laboratory testing procedures, design tools and fault tolerance techniques with respect to system level predicted fault rates and representative locations in natural space radiation environments; and
- Validation that low cost fault tolerance techniques can provide predictable and acceptable levels of reliability for space based COTS onboard data processors while maintaining orders of magnitude performance improvement over state of the art radiation hardened systems in a minimal overhead, scalable architecture.

The design tools, methods and principles of the proposed COTS-based computing investigation must be applicable to future space science missions. Thus, in addition to identifying a particular approach to the validation experiment design, the proposer must discuss the rationale for these choices in terms of applicability to future designs for a broad range of NASA space science missions. NMP envisions that the pathway to maximizing the application envelope and to reducing experiment cost is through developing a scaleable validation experiment and through using validated models to address future designs.

***Flight Validation Rationale*:** There are several aspects of the technology validation experiment requiring a space environment:

a) The full spectrum of natural space radiation cannot be duplicated in the laboratory and the effects are nonlinear, additive, and not well understood at the system level.
b) Due to limitations in particle beam facilities, beam energy levels and physical/packaging constraints, it is not feasible to irradiate a complete system with protons or heavy ions, and it is not feasible to subject a system to multiple types of radiation in any single radiation test facility. Beam experiments are conducted on a single part or, at most, a small number of closely grouped components, which does not provide the system level radiation environment required for validation of a computer system.
c) Use of COTS hardware for onboard science and autonomy computing represents a significant paradigm shift, and there is reluctance to trust the processing of science critical data to a non-radiation hardened machine without empirical evidence of the reliability of such a system.

A.4.2 Science Mission Applicability

The following space science missions have been identified as some of the candidate targets for insertion of this technology listed by science theme:

- ***Exploration of the Solar System (ESS):*** Mars Science Laboratory (MSL), Titan Explorer (TE)
- ***Sun Earth Connection (SEC):*** Magnetospheric Multi-Scale (MMS), Solar Polar Imager (SPI)
- ***Structure and Evolution of the Universe (SEU):*** Energenic X-Ray Imaging Survey Telescope (EXIST), Orbiting Wide-Angle Light-Collector (OWL)
- ***Astronomical Search for Origins (ASO)*:** Terrestrial Planet Finder (TPF)

A.4.3 Representative Space Experience

The current state of the art for radiation tolerant spacecraft computing, for purposes of this solicitation, is defined as the X2000 computing system. Details of the X2000 system can be found at http://x2000.jpl.nasa.gov. Key parameters are:

- Science Computing Capability Estimate: 20 MIPS/W peak, 4-8 MIPS/W sustained;
- Data Throughput: 100 Mb/s Network I/O; and
- Centralized System: no parallel, vector or other high performance processing, and no

22

embedded microcontroller.

A.4.4 Technology Performance Requirements

To ensure that the data obtained from the flight validation can be used to extrapolate to future mission applications, it is desired that the validation experiments have the characteristics shown below:

- Processing Nodes: Minimum of three COTS processors, each with throughput $\geq$ 1000 MIPS *;
- Microcontrollers: COTS-based with integrated ADC and/or general purpose I/O and with throughput $\geq$ 20 MIPS *;
- Network Interconnect: COTS-based interconnect network, supporting > 100 nodes, with network bandwidth $\geq$ 1000 Mb/s *;
- System Software: Operating system and support tools compatible with COTS standard operating systems and development tools generally used for scientific and autonomy codes and for parallel and distributed systems (i.e., Unix, Linux or other file based OS and development environment);
- System level performance: 150 MIPS/Watt with a goal of 300 MIPS/Watt peak, and 100 MIPS/Watt sustained **;
- Radiation Tolerance: Assuming 2.5 mm (100 mil) Al equivalent shielding,
  - System level SEL Immunity to Linear Energy Transfer $\geq$ 75 MeV-cm^2/mg and
  - System level tolerance to TID $\geq$ 70 Krad; and
- Reliability and Availability: Projected five year system reliability and availability 0.999, with a goal of 0.99999 and continued reliable operation in the presence of SEU induced faults at natural space rates assuming a base plate temperature of –10 to +30 °C in LEO, GEO and deep space space radiation environments with no solar flare activity.

* Theoretical Max

** Benchmarks to be suggested by provider, with subsequent negotiation between the ST8 Project Manager and technology provider at start of Formulation Refinement Phase to arrive at a mutually acceptable set of benchmarks.

The desired performance requirements listed above are consistent with the desired validation experiment, but do not necessarily constitute the only possible approach. Proposers are encouraged to identify alternative approaches or subsets of the above if they can be shown to adequately validate the technology and be more cost effective.

A.4.5 Representative Measurements, Parameters, and Model Verification

The ultimate goal of this investigation is to validate and/or calibrate the underlying technology models proposed for this experiment, as well as to validate the efficacy of the fault tolerance techniques and system design methods and tools. In order to accomplish this, the following parameters are suggested as a minimum set to be measured by the investigation:

- Fault rates;
- Fault locations where fault sites are identified with sufficient physical (hardware) granularity to aid in diagnosing the system;
- Radiation environment;
- Number of successful recoveries from recoverable faults;
- Recovery time;
- Number of system failures which cause the system to cease operating due to unrecoverable faults; and
- Effective MIPS/Watt at the system level in the presence of recoverable faults.

The above are suggestions and no claim is made that they represent a necessary or sufficient set. Proposers are encouraged to tailor their measurements to their technologies, experimental systems and validation needs.

THIS PAGE INTENTIONALLY LEFT BLANK

THIS PAGE INTENTIONALLY LEFT BLANK

END

02-13-04